MEMO

Subject: JHD Processing of Event Clusters

From: Hans Israelsson, CMR

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In this memo we describe briefly one of the procedure used in the Group 2 Consortium for constructing station path corrections from clusters of well-located events. This procedure uses a Joint Hypocenter Determination (JHD) algorithm, *jhd89*, by Dewey (1972, 1989) applied to ISC (2001) and NEIS (2001) first arrival P data screened for outliers.

COMPILATION OF EVENT CLUSTER DATA

Compilation of data for an event cluster is driven by a reference event in category GT5 or less. With that event as a starting point the ISC and NEIS event catalogs on their web pages are searched for candidate cluster events within 35 km and with a depth less than 40 km. The ISC catalog is searched from 1970 up to the most recent monthly bulletin and the NEIS catalog is searched from that time to the date of the data of processing. Events selected as candidates have also to be well recorded by imposing the requirement that for ISC events the number of defining arrivals, *ndef* > 25 and that for NEIS events the magnitude > 4.0. The events are ranked according to *ndef* or magnitude and those with the largest values are selected for the event cluster. The number of events in a cluster is typically around 25, but larger event clusters are also processed as the original *jhd89* algorithm was extended to handle up to 100 events with arrivals at up to 500 stations. The search parameters - maximum distance from reference event, minimum *ndef*, etc. - are, for some clusters, adjusted from the values above, which can be regarded as default settings.

JHD COMPUTATIONS

The IASPEI91 travel time tables are used in the computations and neither elevation nor ellipticity corrections are applied. The hypocenter and origin time of a reference event is held fixed. This means that the time base for estimated station path corrections is controlled by the origin time of this reference event. If additional reference events are available their hypocenters are also held fixed. The depths of non-reference events are held fixed at that of the main reference event. This means that the processing is effectively a joint epicenter determination and not a joint hypocenter determination.

Prior to application of the program *jhd89*, station arrivals with residuals larger than 15.0 sec in the ISC and NEIS bulletins are removed. Only arrivals recorded at a distance larger than 5 times the prescribed maximum diameter of the event cluster (usually 50 km) and less than 90 degrees are used in the subsequent processing. Furthermore Group2 stations (including surrogates) and IMS stations have to have arrivals for 5 or more events. A minimum of 10 arrivals are required for other stations.

A weighting of station arrivals, used in the first three of the 8 iterations of the *jhd89* computation, is determined from the arrival time residuals as reported in the ISC/NEIS bulletins. The weight for a station is based on the standard deviation of these residuals. The inverse of the squared value of

the standard deviation rounded up to the nearest half a second is used as a weight in the three first iteration of each jhd89 run. In cases with standard deviations larger than sqrt(10), the standard deviation is assigned sqrt(10).

After the initial run with *jhd89* the diameter of the resulting event cluster is compared with the prescribed value and outlying events are excluded in the subsequent processing. Possible outliers among associated arrivals are also removed using distance dependent cut off values (see Figure 1). This step of removing arrivals is followed by a standard outlier test (kurtorsis test at 1% level, Barnett and Lewis, 1980), but arrivals failing this latter test with residuals less than 1.0 sec are retained. Stations for which more than one third of the arrivals are rejected are omitted entirely in the subsequent processing. After this data editing the *jhd89* is applied a second time, which is again followed by possible outlier rejection and adjustment of the event cluster to be within the prescribed diameter. Typically less than 10% of the original arrivals are rejected by the outlier screening. A final and third run with *jhd89* is then carried out.

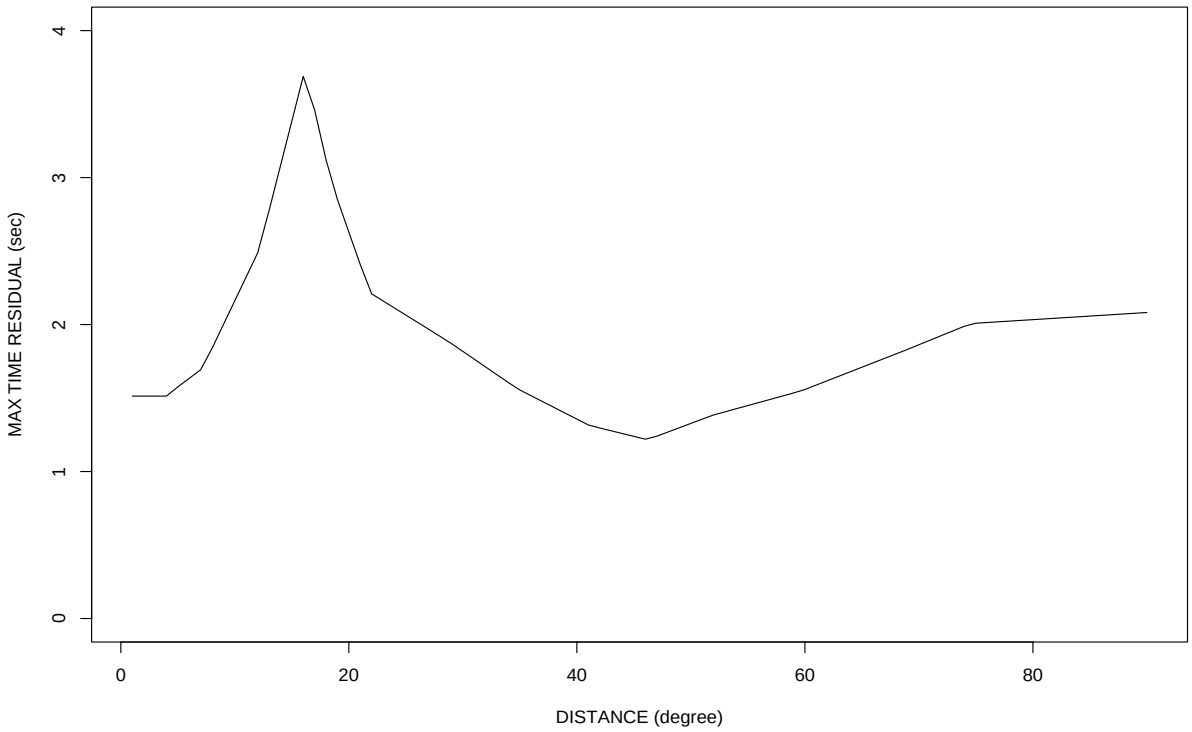

Figure 1. Cut off limits for removal of outliers as a function of epicentral distance. The curve was derived from the standard deviation arrival time residuals of 25 JHD event clusters without outlier removal multiplied by a factor of 3.29 corresponding to 0.1% level.

EXAMPLES WITH REFERENCE EVENT CLUSTERS

Results of JHD locations of 4 small event clusters consisting of reference events of ground truth category 1 or 2 are summarized in Table 1. Ground truth information for three of the clusters, all nuclear explosions, was reported by Sultanov et al. (1999) and for one of the clusters, mining

explosions in Poland information was provided by Gibowicz (2000). One event was held fixed for each cluster. The table gives location errors and error ellipses (90% confidence level) and it also shows that the error ellipses covered the ground truth location (accounting for the GT uncertainty of 1 or 2 km) for 28 out of the 32 events of the clusters combined.

REFEENCES

Barnett, V and T Lewis, 1980, Outliers in Statistical Data, John Wiley & Sons, New York.

Dewey, J.W. (1972), Seismicity and tectonics in western Venezuela, BSSA, 62: 1711-1751.

Dewey, J. W. (1989), JHD89 and SE89 - Algorithms for Joint Hypocenter Determination and modified Single-Event Determination (Memo USGS).

ISC (2001), http://www.isc.ac.uk

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Sultanov, D. D.; Murphy, J. R.; Rubenstein, K. D. (1999), A Seismic Source Summary for Soviet Peaceful Nuclear Explosions, BSSA 89: 640 - 647.

Table 1: JHD Location Results of 4 Event Clusters consisting of Reference Events

Date Time	Reference Event		JHD Location		Error[a]		Cover[b]
	Epicenter	GT	Epicenter	Error Ellipse[c]	*D*t (s)	*D*d (km)	
Astrakhan, Caspian Sea							
1980/10/08 06:00:00.3	46.757 48.275	1	46.757 48.275				
1981/09/26 05:00:00.3	46.790 48.313	1	46.797 48.302	2.8 2.3 8	-0.08	1.1	1
1981/09/26 05:03:59.9	46.771 48.304	1	46.807 48.287	2.8 2.3 6	0.10	4.2	1
1982/10/16 06:00:00.1	46.759 48.247	1	46.764 48.246	2.5 2.1 18	0.00	0.6	1
1982/10/16 06:05:00.1	46.752 48.258	1	46.744 48.237	2.5 2.0 19	0.12	1.8	1
1982/10/16 06:10:00.1	46.766 48.288	1	46.773 48.265	2.5 2.0 19	0.12	1.9	1
1982/10/16 06:15:00.2	46.760 48.300	1	46.751 48.272	2.5 2.0 21	0.02	2.4	1
1983/09/24 05:00:00.0	46.783 48.315	1	46.797 48.294	2.8 2.1 10	0.10	2.2	1
1983/09/24 05:05:00.0	46.788 48.297	1	46.799 48.270	2.8 2.1 10	0.15	2.4	1
1983/09/24 05:10:00.1	46.767 48.310	1	46.776 48.310	3.0 2.1 3	-0.01	1.0	1
1983/09/24 05:15:00.1	46.749 48.303	1	46.784 48.274	2.8 2.1 11	0.12	4.5	0
1983/09/24 05:19:59.9	46.754 48.289	1	46.796 48.264	2.8 2.1 11	0.26	5.0	0
1983/09/24 05:25:00.0	46.766 48.274	1	46.774 48.299	3.0 2.3 358	-0.13	2.1	1
Azgir, Caspian Sea							
1971/12/22 06:59:59.0	47.897 48.133	1	47.896 48.120	2.0 1.8 6	0.16	1.0	1
1976/07/29 05:00:00.5	47.870 48.150	1	47.867 48.109	1.9 1.8 12	-0.03	3.1	0
1977/09/30 06:59:58.4	47.897 48.161	1	47.897 48.161				
1978/10/17 04:59:59.1	47.850 48.120	1	47.835 48.097	1.9 1.7 9	0.09	2.4	1
1978/12/18 07:59:58.5	47.860 48.160	1	47.835 48.152	1.9 1.7 11	0.61	2.8	1
1979/01/17 07:59:58.5	47.920 48.120	1	47.906 48.103	2.1 1.8 10	-0.32	2.0	1
1979/07/14 04:59:58.0	47.880 48.120	1	47.875 48.100	1.9 1.8 9	-0.13	1.6	1
1979/10/24 05:59:59.0	47.850 48.140	1	47.841 48.117	2.0 1.7 8	0.38	2.0	1
Orenburg, Russia							
1983/07/10 03:59:60.0	51.363 53.306	1	51.363 53.306				
1983/07/10 04:04:59.9	51.367 53.327	1	51.368 53.312	1.6 1.3 343	0.00	1.1	1

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	Epicenter	GT	Epicenter	Error Ellipse[c]	*D*t (s)	*D*d (km)	
1983/07/10 04:09:59.9	51.380 53.340	1	51.381 53.324	1.6 1.3 343	0.10	1.1	1
1984/07/21 02:59:59.8	51.358 53.319	1	51.367 53.309	1.6 1.3 347	0.00	1.2	1
1984/07/21 03:04:59.7	51.371 53.337	1	51.396 53.335	1.5 1.3 348	-0.02	2.8	1
1984/07/21 03:09:59.9	51.391 53.351	1	51.384 53.324	1.6 1.3 343	0.00	2.0	1
Lubin, Poland							
1995/11/23 05:02:28.5	51.482 16.093	1	51.490 16.085	2.8 2.4 85	0.83	1.1	1
1996/03/16 05:09:36.9	51.449 16.103	1	51.474 16.099	3.2 2.7 63	-0.05	2.8	1
1996/03/21 16:30:51.6	51.543 16.024	1	51.571 16.003	3.0 2.8 81	0.15	3.4	1
1996/03/25 20:31:45.4	51.474 16.080	1	51.495 16.086	2.5 2.2 85	0.15	2.4	1
1997/05/13 18:37:05.0	51.468 16.122	1	51.491 16.117	2.5 2.1 79	0.08	2.6	1
1998/04/17 03:21:18.4	51.524 16.027	1	51.527 16.010	2.5 2.1 78	0.43	1.2	1
1995/05/26 02:57:25.6	51.530 16.120	2	51.593 16.130	3.9 2.5 34	1.57	7.0	0
1999/09/21 14:36:06.6	51.468 16.112	1	51.472 16.100	2.8 2.5 77	0.52	0.9	1
2000/01/22 20:30:59.0	51.486 16.088	1	51.492 16.090	2.7 2.4 65	0.16	0.7	1
2000/02/25 00:14:56.7	51.511 16.079	1	51.517 16.072	3.1 2.6 60	0.13	0.8	1
2000/07/18 03:44:06.0	51.506 16.136	1	51.506 16.136				

a. Error in origin time, *D*t in seconds and epicenter, *D*d, in km.
b. Coverage parameter indicating overlap of JHD error ellipse and circle around reference event with radius GT overlap (=1 if overlap, =0 no overlap).
c. 90% semi-major, semi-minor axes (km) and strike (in degrees from North).